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The Value of Evidence-Based Computer Simulation of Oral Health Outcomes for Management Analysis of the Alaska Dental Health Aide Program.

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Abstract

Objectives: To create an evidence-based research tool to inform and guide policy and program managers as they develop and deploy new service delivery models for oral disease prevention and intervention.

Methods: A village-level discrete event simulation was developed to project outcomes associated with different service delivery patterns. Evidence- based outcomes were associated with dental health aide activities, and projected indicators (DMFT, F+ST, T-health, SiC, CPI, ECC) were proxy for oral health outcomes. Model runs representing the planned program implementation, a more intensive staffing scenario, and a more robust prevention scenario, generated 20-year projections of clinical indicators; graphs and tallies were analyzed for trends and differences.

Results: Outcomes associated with alternative patterns of service delivery indicate there is potential for substantial improvement in clinical outcomes with modest program changes. Not all segments of the population derive equal benefit when program variables are altered. Children benefit more from increased prevention, while adults benefit more from intensive staffing.

Conclusions: Evidence- based simulation is a useful tool to analyze the impact of changing program variables on program outcome measures. This simulation informs dental managers of the clinical outcomes associated with policy and service delivery variables. Simulation tools can assist public health managers in analyzing and understanding the relationship between their policy decisions and long-term clinical outcomes.

MeSH keywords: computer simulation, computer model, decision analysis, dental care delivery, health status indicators, outcomes assessment, outcomes research

Introduction

Changes in the Alaska Native diet and low natural fluoride concentration in drinking water have contributed to an incidence of tooth decay among rural Alaska Native peoples that is estimated to be two and a half times the national rate (1). Smoking and inadequate dental hygiene contribute to a high rate of periodontal disease (2). To help address significant oral health disparities experienced within the Native community a new dental program was recently implemented in rural Alaska.

The new delivery model utilizes health aides to deliver components of dental care in rural areas. Dental health aides (DHA) are trained personnel who work in various clinical capacities under the general supervision of a dentist. The DHA program replaces an earlier service delivery model patterned after the Indian Health Service Dental Program. The earlier program was a network of itinerant dentists, hygienists and auxiliaries who provided treatment in remote and frequently temporary clinics. Most villages were visited just once or twice a year and pediatric care was the priority. Access to rural regional dental clinics is hampered by difficult long distance travel and the vagaries of Alaska weather. The program suffered chronic personnel shortfalls and left a substantial backlog of untreated dental disease (3).

The DHA program was developed to overcome these barriers. The program trains a local advocate, a primary dental health aide (PDHA), to provide oral health promotion and disease prevention in rural villages. Typically, they work in their home village and are already familiar and comfortable with village life, culture and language. In this model of service delivery, DHAs are trained in specific activities, delivering more services under general supervision than auxiliaries did previously. Activities include application of fluoride varnish and sealants, prophylaxis, school-based oral health promotion, and outreach to new parents and the homebound. The goal of program developers is to increase therapeutic capacity, address the difficult geographic distribution of the patient population, provide preventive measures in a more effective manner, and ultimately to decrease the prevalence of untreated disease (1). Eventually, all larger villages might choose to employ a PDHA.

Even before their innovative program was deployed, the managers recognized that they wanted to improve their understanding of the linkages between service delivery policies and clinical outcomes. However, the DHAs were yet to be trained and their impact on patient's oral health and function would require years to observe. A lack of information linking alternative strategies with likely or potential outcomes may result in ineffective programs, less than optimal clinical outcomes, compromised economic outcomes and public health uncertainties. Because of the substantial lag between health behaviors and measurable health outcomes, a computer simulation of the clinical impact was developed.

The clinical impact model is a computer simulation of the DHA program implemented in Alaska. The model was developed to identify the determinants and linkages that are associated with dental health outcomes and to examine the impact of altering policy variables through a process of dynamic analysis. The Alaska Native Tribal Health Consortium (ANTHC) Dental Support Center and the University of Alaska Anchorage Institutional Review Board (IRB) approved this project.

Methods

The clinical impact model utilizes discrete event simulation software (XJ Technologies AnyLogic 5.3, AnyLogic North America LLC, Boston) to analyze the relationship of program variables to the anticipated clinical outcomes of the program. Variables for this simulation include training timeline horizons, clinic staffing-levels, beneficiary participation and dental health behaviors. The output describes changes in the oral health status of the population over time and shows patterns and systematic differences in clinical outcomes between alternate delivery models.

Evidence-based logic

The logic controlling the behavior of the simulation is a set of decision rules and assumptions. The rules are supported by applicable evidence-based findings in published peer-reviewed English language literature when available, supplemented by informed professional judgment of the developers and the client. Rules can be readily updated when new evidence or technology supports a change in the relationship between program variables and clinical outcomes.

The simulation incorporates 70 variable parameters associated with the scenario being analyzed. Table 1 is a list of selected parameters. Variables include staffing and referral patterns of PDHA and itinerant providers, certified scope of practice, the duration and frequency of health activities and behaviors, and social variables such as the impact of fishing season on clinic attendance. Because the user can alter parameters, the model can be readily modified to simulate situations in different villages, regions and communities. Detailed description and documentation for the model is available at www.iser.uaa.alaska.edu/projects/dha_model/

The logic governs how the simulation models the incidence, prevalence and distribution of disease, the estimated effect of activities, and the staff development and coordination required to deliver them. Simulation output, in the form of graphs and tallies, records indicators of oral health status distributed by age group, patient visit and service delivery counts, and dental workforce utilization. A portion of the output is captured in an Excel spreadsheet and a portion is retrieved from the simulation screen. Through this method of comparative dynamics, managers assess the impact of alternative service delivery parameters on program output and indicators of clinical outcomes.

Incremental changes in oral health indicators of the prevalence and distribution of oral disease and treatment are used as proxy to express potential changes in health outcomes. These include the caries index or DMFT (the sum of decayed, missing due to decay, and filled teeth), functional index or F+ST (the sum of filled and sound non-decayed teeth), and T-health (a weighted value based on the present status of each tooth). Although we commonly use the caries index to compare outcomes, the functional index can be more useful than the caries index for describing variation in populations with high levels of disease (5).

Additional indicators include the significant caries index or SiC (the mean DMFT of the one-third of the population with the highest DMFT), the community periodontal index or CPI (derived periodontal status based on reversible and irreversible criteria) and ECC (the percentage of children exhibiting early childhood caries). The World Health Organization has proposed that SiC should be less than 3 by the year 2015 (6).

Because the previous dental health system preferentially treated children, many adults did not receive adequate care for periodontal disease. In the DHA program, children continue to receive priority care. A PDHA provides routine preventive services and the hygienist is able to treat cases that are more complicated. In this way PDHA have an impact on the delivery rate of therapies that are beyond their scope of practice.

Data

The simulation projects health outcomes over twenty years beginning January 1, 2000 and permits observation of how the oral health delivery system may perform over a long period. This start date captures the period immediately before and during the development period of the DHA program within the 20-year life of each simulation.

The baseline demographic data for the village simulation were extracted from the 2000 U.S. Census data (4) aged over twenty years with births, deaths, and migration. The baseline oral health epidemiological data were extracted from the 1999 Indian Health Service Alaska Area oral health survey, and were provided by ANTHC. Survey characteristics include the number of fillings, number of missing teeth, number of surfaces with untreated decay, periodontal status, and other oral health characteristics. The sample size was calculated to provide a margin of error in adult age groups of one tooth, and a margin of error on child age groups of one-half tooth (2). The survey data include epidemiological data for 1160 Alaska Native dental clinic patients believed to be representative of patients who attend Alaska Tribal dental clinics.

Simulation

To demonstrate the clinical impact model at the village level, three implementation scenarios were developed and simulated. The village is the same in each scenario and each simulation run begins in year 2000. The village has a one-chair clinic, a baseline population of just over 1000 in year 2000, and approximately half of the residents are female. Baseline ages in year 2000 range from younger than one year to older than 85 years with a median age of 18 years. The simulation output indicates the changes in the oral health status of the population over time.

The utilization of a resident PDHA is one groundbreaking change in this new oral healthcare system. To analyze the impact of this onsite prevention agent, the first scenario, “planned implementation”, uses variables that are similar to those proposed for a typical village deployment. The simulation generates 20-year health outcomes both with and without the PDHA.

The second scenario, “more intensive staffing”, simulates efficiencies and staffing variables that a manager might explore in examining their linkage to health outcomes. PDHA and professional staff hours are increased, the length of clinic appointments is reduced, and the maximum output of personnel is increased to examine the potential impact of full staffing and high productivity.

The final scenario, “more robust prevention”, was crafted to demonstrate how a manager might examine the impact of newly developed preventive measures, or estimate the impact of delays in deploying innovative health behaviors. In the third scenario the staffing variables are returned to the planned implementation levels, an additional prevention program is introduced, and other health activities are implemented earlier.

Results

For each scenario, we identify the main characteristics, present selected simulation model output, and summarize highlights of the associated health outcomes.

Scenario One—Planned Implementation

The parameter values resemble the planned implementation. One PDHA enters the village in 2006 and works 17.5 hours per week. Work hours are reduced to 12.5 during summers when patient demand declines to 66% of normal. In 2007, the PDHA earns sealant, prophylaxis and radiology certifications. In 2011, the PDHA begins working 40 hours per week, 26 hours per week in summer. The PDHA performs the full authorized and certified scope of practice including clinic, school and community based activities. During their visits, itinerant dentists and hygienists fully utilize the clinic for a total of sixteen weeks each year.

Scenario One Output. Compared to the prior delivery program, 20% more of the child population (from 75% to 90%) and two and a half times as much of the adult population (20% to 50%) receive care in the clinic. 70% more (53% to 90%) of children receive oral health promotion and disease prevention outreach (Figure 1). The mean DMFT for the young adult population decreases by 33% (7.4 to 4.9). Of children, 7.7% remain caries free, compared to 1% when the PDHA begins. The SiC in children is reduced by 50% (12.3 to 6.1), and in 12-year-olds it is reduced by nearly 70% (10.5 to 3.3).

Although the prevalence of decay in adults continues to increase over time, compared to the DMFT projected without a PDHA the caries index (Figure 2) for the adult population declines (18.1 to 16.5). There is a sixteen-fold increase (2.8% to 45.3%) in the percent of adults who experience improvement in periodontal status.

The health outcomes associated with the first scenario are an increase in the amount of oral health promotion and disease prevention received, an increase in the mean periodontal health among adults, a decrease in the amount of new decay and the prevalence of decay in 12-year-olds, and improved function and oral health.

Scenario Two—Intensive Staffing

Relative to scenario one, staff hours are increased, the length of clinic appointments are shorter, and the maximum output is greater to examine the impact of full staffing and higher productivity. Efficiencies improve the productivity of the hygienist and dentist throughout the simulation. Beginning in 2006 the PDHA works 40 hours per week (26 in summer). The PDHA and hygienist provide their services in shortened appointments utilizing unspecified efficiencies. The dentist restores more teeth per appointment. These changes might also be accomplished by utilizing additional DHAs.

Scenario Two Output. Compared to scenario one, the percent of adults receiving clinic care triples (from 20% to 60%). The mean DMFT declines for all, but especially for adults (from 16.5 to 14.9). The SiC for 12-year-olds in 2020 is 3.1. An increase in functional index (F+ST), which is more suited than DMFT in describing variation in populations with high level of disease (5), indicates increased restoration and preservation of functioning teeth. Compared to the baseline (Figure 3), the F+ST improves for all in the intensive staffing scenario, especially for an older cohort (from 16.8 to 22.6). By 2010 59% of adults get their teeth cleaned annually compared to 17% in scenario one. The percent of adults with an improved periodontal status indicator reaches 63% by 2010. Of the 30% of the adult population with periodontal disease, about one quarter receive appropriate therapy.

The health outcomes associated with scenario two are a higher percent of adult patients receive desired care, an increase in the mean periodontal health of the adult population (Figure 4), a decrease in new decay in the adult population, and an increase in the mean number of functional teeth among adults.

Scenario Three—Robust Prevention

The staffing is at the levels of the planned implementation in scenario one. Compared to scenario one, an additional outreach program (postprandial xylitol gum) is deployed, and the implementation dates for other programs are changed to examine the potential effect of more intensive prevention strategy.

Scenario Three Output. Relative to the previous scenarios (Figure 1), the impact on the percent of children who remain caries free in this scenario is large (Figure 5). The percent of children 5-18 who remain caries free in 2020 is 51%, compared to 7.7% in scenario one and 7.9% in scenario two. The SiC of children is reduced from 12.7 in 2007 to 4.7 by 2020, compared to 6.1 in scenario one. The SiC of 12-year-olds is projected below 3 prior to 2015 and declines to 2.2 by 2020, achieving a WHO goal. The changes in this scenario have little impact on health indicators for the current adult population, because the preventive measures primarily focus on newborns and school-aged children.

The health outcomes associated with changes in scenario three are a decrease in new decay in children, a decrease in prevalence of decay in twelve-year-olds, and for more than half of the child population the experience of remaining caries free and enjoying full dental function.

Discussion

Herman et al. utilized a Markov computer simulation model to extrapolate health outcomes associated with medication and lifestyle variables in the prevention of diabetes in adults (7). Markov models utilize fixed time intervals and transition states to model change. The rigidity of these pre-defined states appears less suited for modeling evolving change of oral health outcomes.

Stahl, Roberts and Gazelle utilized discrete-event simulation to evaluate and optimize the flow of patients through a health clinic by comparing alternative staffing strategies (8). Their outcomes of interest were clinic revenue and wait times. Lee et al. utilized a discrete-event simulation model to identify optimal staffing and resource allocation based on hourly patient flow in alternative scenarios

(9). Zhang, Meltzer and Wortley developed a computer modeling tool to estimate hospital admissions and deaths under alternative scenarios of pandemic influenza (10). Scherrer, Griffin and Swann utilized discrete-event simulation of a sealant program to optimize resource utilization and project economic outcomes (11).

We believe we are reporting the first evidence-based computer simulation tool to model evolving changes in health outcomes.

Implications for health policy. The scenarios demonstrate how variables in the clinical impact simulation (such as health behaviors, workforce variables, clinic schedules, and outreach implementation horizons) could be arranged to reflect actual or planned practices (such as efforts to serve more patients, decrease new decay, decrease untreated decay and improve function, improve dental hygiene access). For all three scenarios, the possible implications include reduced public health expenses related to urgent care, and reduced population exposure to antibiotics and pain medication and their associated complications. Improvement in the periodontal status of the adult population, and increased exposure to health promotion and disease prevention activities, reduces risk for related health issues that may include cardiac and respiratory disease and complications of pregnancy and diabetes. Improvement in the population's dental function reduces a barrier to improvements in nutritional status and related health benefits, and this will be perceived as improvement in quality of life (12).

Implications of clinical impact simulation for management decision-making. The process of developing a simulation model is an effective method for cultivating an understanding of the components, policies and norms, practices and language, and objectives and goals of a public health program. The sequential evaluation of the operational details and internal relationships of a program can lead to insights that may also serve to inform and clarify decision-making. When operating as a computer simulation, the model is a tool that informs managers how the health system behaves and enables them to compare its output under different sets of assumptions and situations. The simulation can be easily updated with new evidence, and it can be readily modified to simulate different assumptions and situations.

This new tool can be employed to assess the linkage between clinical and administrative changes and decisions, and estimate their effect on both program measures and health outcomes. More effective programs and improved clinical outcomes are more likely to occur.

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Table 1. Selected parameter variables. An example of management variables that may be altered to examine linkages to health outcomes. Seventy such variables were developed for the village level DHA simulation.

PDHA factors

Hours per week PDHA will be employed during summer

The year PDHA becomes certified to take radiographs

The year PDHA increases hours to "full time" during winter

Dentist and Hygienist factors

Maximum number of restorations per appointment

Frequency of hygiene field trips to village per year

Length of average appointment, minutes

Health Behaviors

Factor by which care seeking decreases in summer

How long are people willing to wait to be seen before leaving

How much time is devoted to school-based varnish outreach

Treatment factors

The rate at which current sealant material is failing

The year Chlorhexidine rinse will be available to prescribe for new mothers

Year Xylitol gum will be dispensed to all children